The 10G TTC-PON: Challenges, Solutions and Performance

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Outline

- Introduction to TTC-PON

- System Challenges & Solutions

- TTC-PON Core

- Conclusions

- Potential Developments for Phase-2

Current TTC System

o TTC = Timing, Trigger and Control

    o Designed in ~2000

o <u>Unidirectional</u> system (optical) / 1310nm

o 1:32 split ratio maximum

o <u>Low bandwidth:</u> 80Mb/s

o Busy/throttle on a separate link
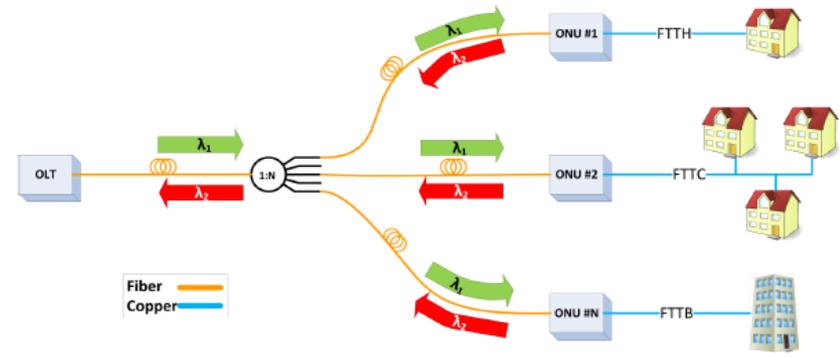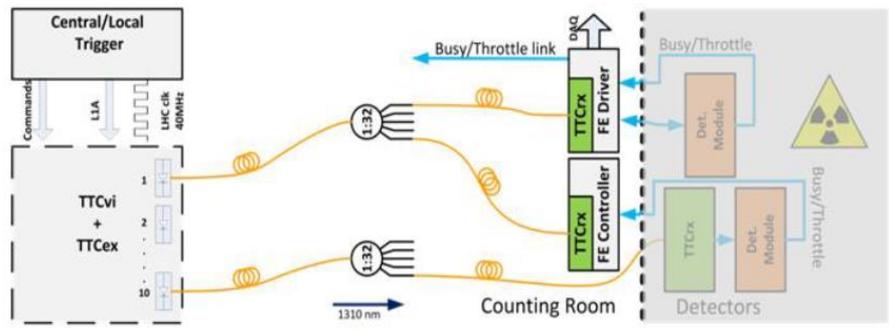
Too limited for phase1/2 upgrades
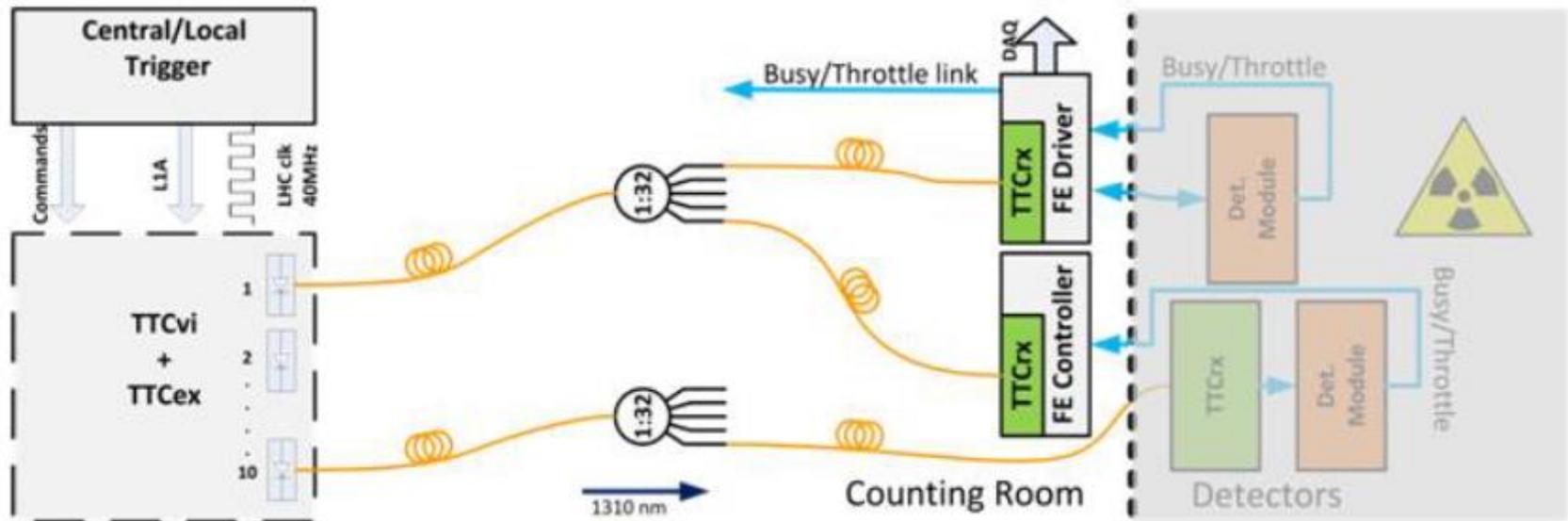
PON Basics

o PON = Passive Optical Network
  o Used in FTTH

o Point to Multipoint Network (P2M)
  o <u>Bidirectional</u> / WDM: 1 fiber, 2 wavelengths (1 Up, 1 Down)

o Downstream (OLT->ONU)
  o <u>High bandwidth</u>

o Upstream (ONU->OLT)
  o Low & shared bandwidth
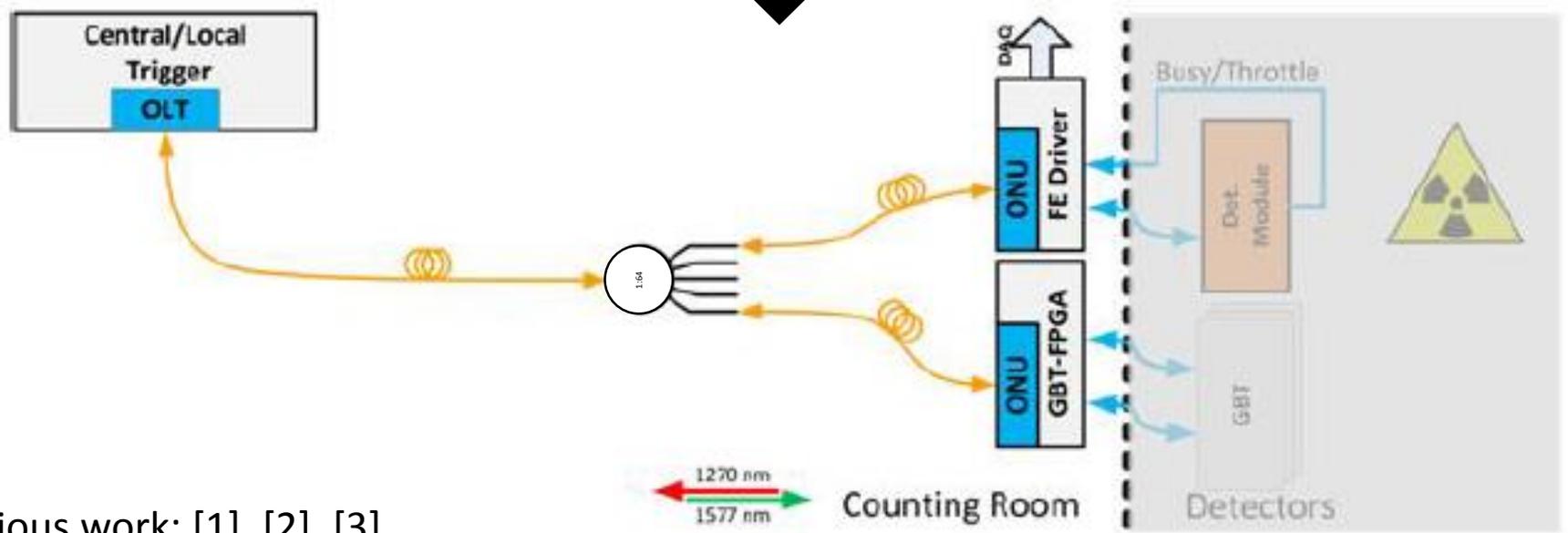 o Arbitrated by OLT
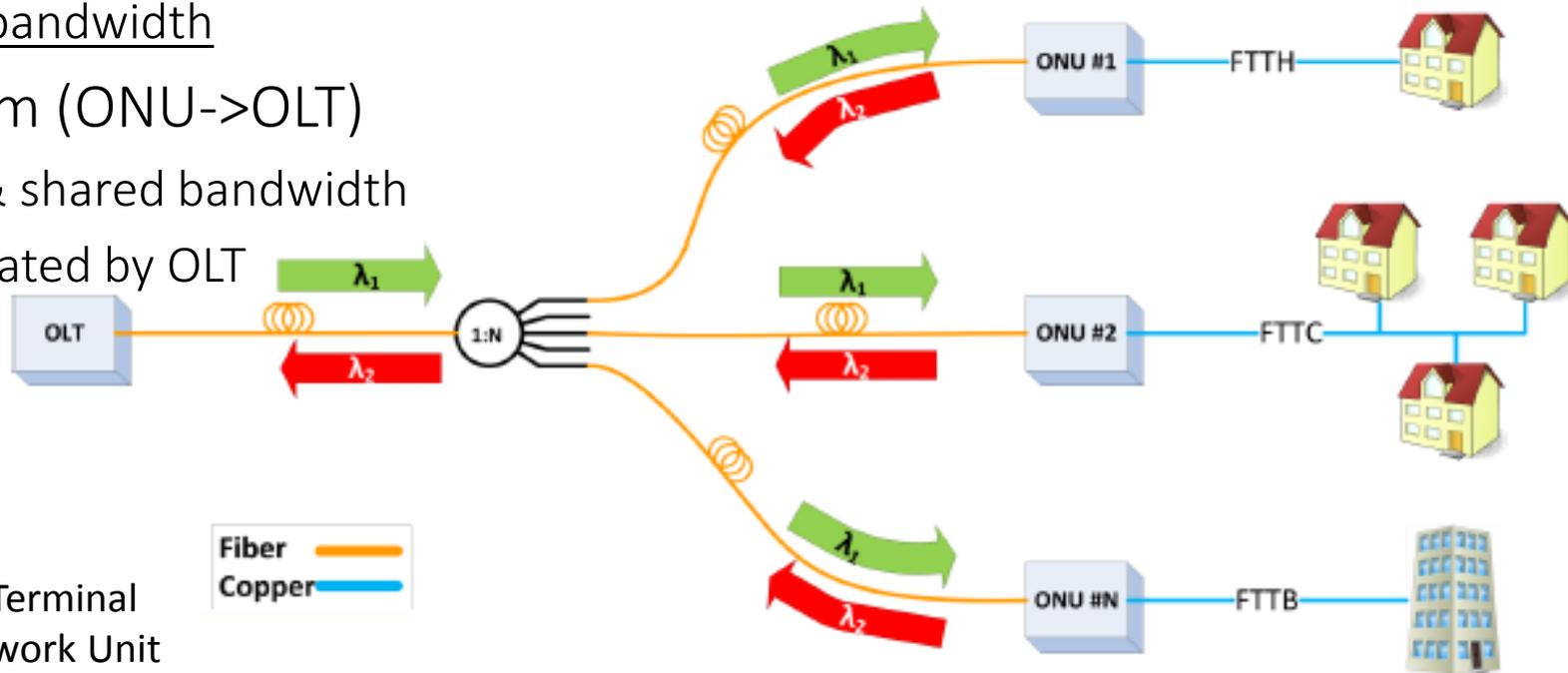
OLT=Optical Line Terminal
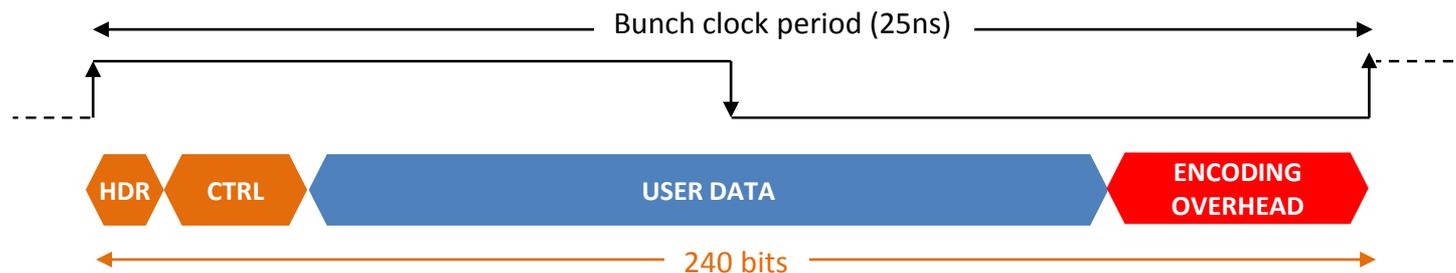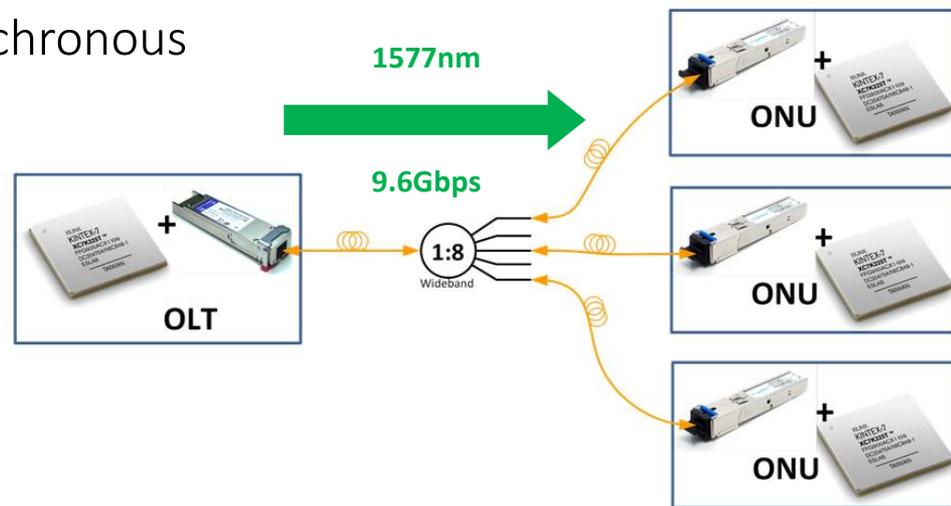ONU=Optical Network Unit

TTC-PON System

- Previous work: [1], [2], [3]

Downstream path

o OLT → ONUs (continuous transmission)

o 9.6Gbps serial link (240 raw bits per BC / 8b header, 24b – control)

o LHC Bunch Clock (BC) synchronous

o Fixed & Low latency

o High bandwidth

1577nm

9.6Gbps

OLT

1:8
Wideband

ONU

ONU

ONU

Bunch clock period (25ns)

10G PON-TTC

| HDR | CTRL | USER DATA | ENCODING OVERHEAD |

240 bits

* Not in scale

Downstream path

o Challenges:

    o PON Standard line rate close multiple of 40MHz

    $\Rightarrow$ XGPON (9.8Gbps $\rightarrow$ TTC-PON – 9.6Gbps)

    o Deterministic latency

    $\Rightarrow$ Careful choice PLL

    $\Rightarrow$ FPGA transceiver buffer bypass

    $\Rightarrow$ Recovered clock alignment to header

    o Small optical margin with simple 8b10b

    $\Rightarrow$ Scrambling + FEC (Forward Error Correction)

        $\Rightarrow$ Target margin ~ 3dB (conservative approach)

For 100m fiber

Downstream path

TTC PON
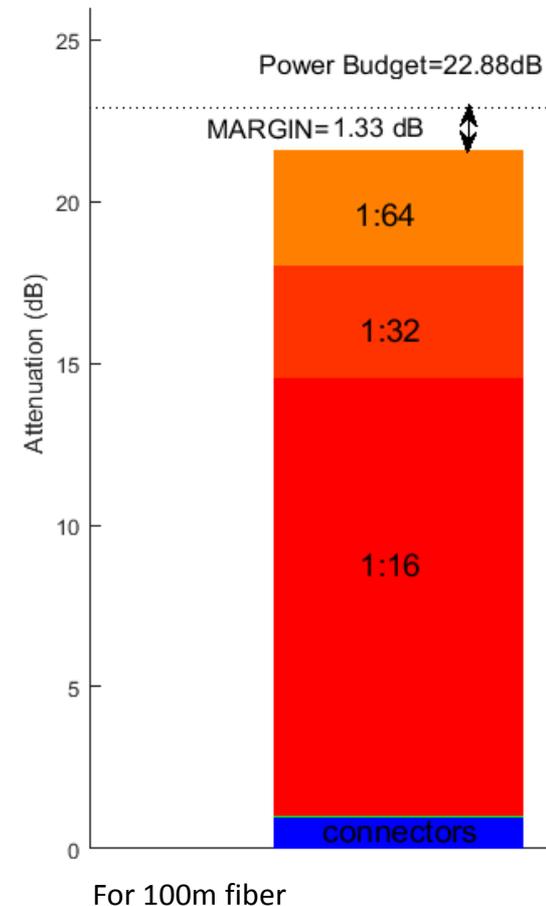
Errors observed seem to have random nature (different from GBT environment)

o Binary BCH codes are good for correcting random errors with a relatively low complexity [5]

n-bits

INFORMATION – k bits | PARITY

o Systematic encoding: BCH(n,k)

o Four shortened-BCH codes were evaluated:
- o BCH(40,34)
- o BCH(80,73) } Single-error correcting
- o BCH(120,113)
- o BCH(120,106) } Double-error correcting

o Main Figures of merit:
- o Efficiency (k/n)
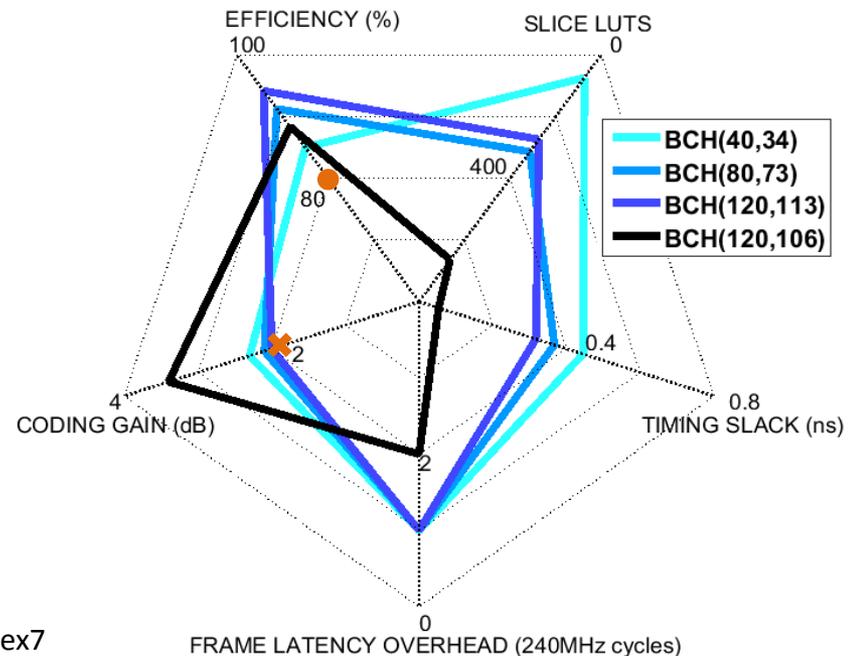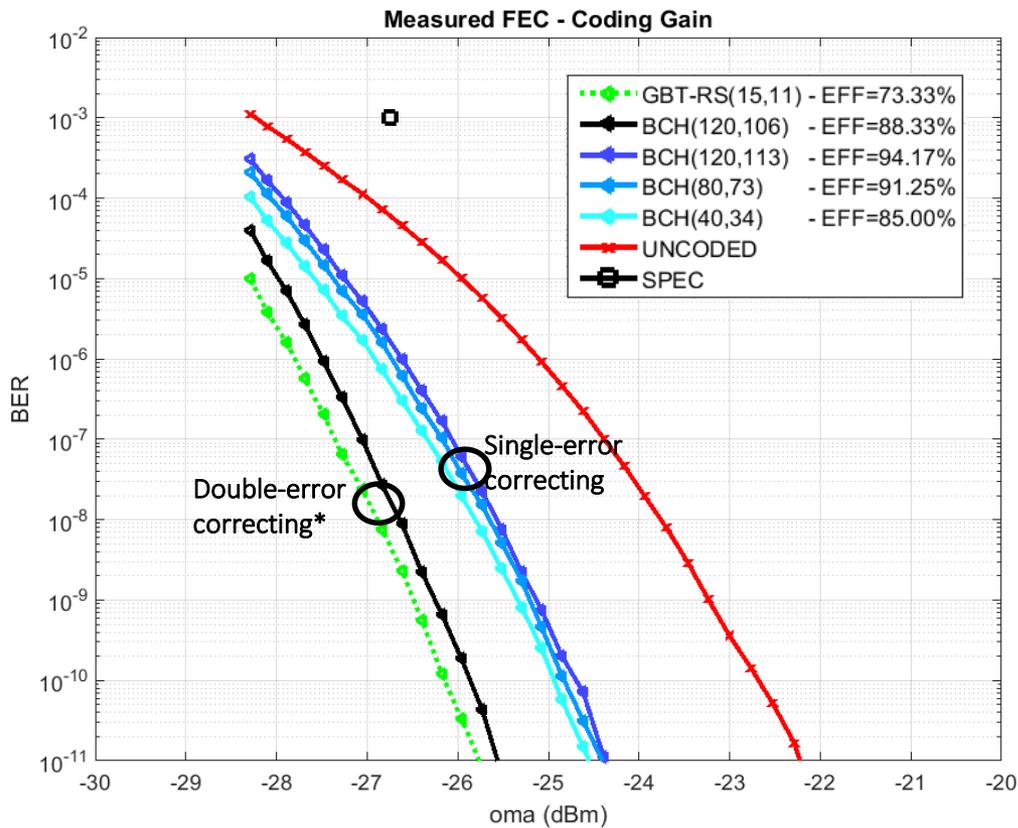- o Coding gain
- o Latency
- o Timing
- o Complexity (area)

o Scrambling: signal randomizer

o Self-synchronous scrambling: no sync. overhead but error multiplication...

Scrambler → FEC encoder → Channel → FEC decoder → Descrambler

Downstream path

o Measurements Results:

Measured FEC - Coding Gain

* RS(15,11) can correct two four-bit symbols

- Decoder parameters considered for latency, slice luts and timing slack on Kintex7
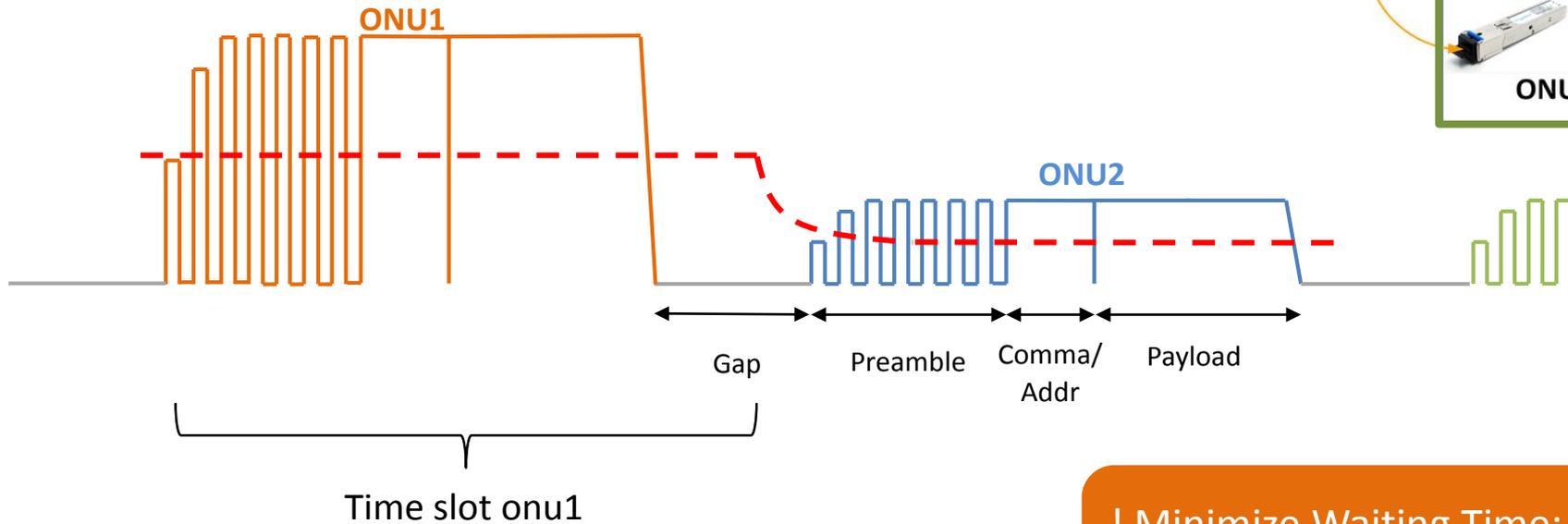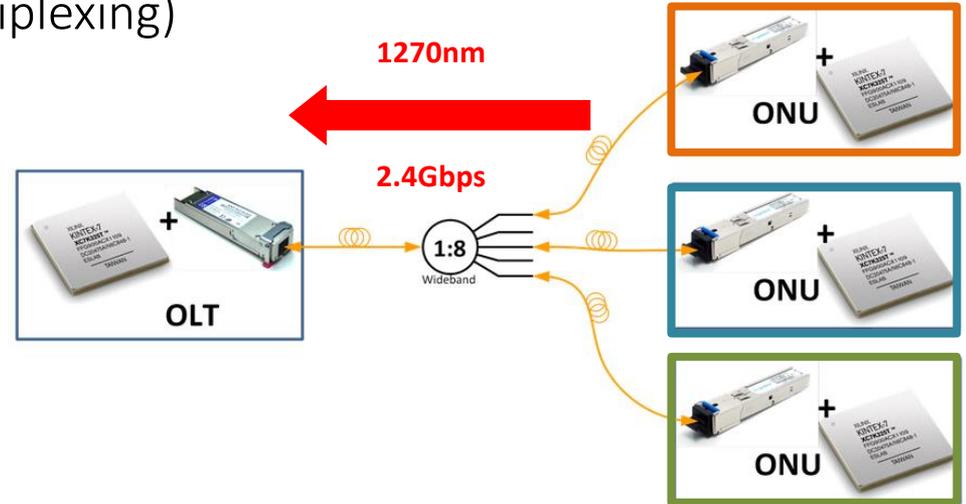
Downstream path

o Summary:

| Downstream Performance Summary		
Encoding scheme	8b10b	FEC
Line-Rate	9.6Gbps – sync. to bunch clock	
Latency	Fixed and deterministic [4] (value to be characterised with FEC)	
Power Budget	22.88dB (8b10b)	~25.05dB (worst-case BCH(120,113)) ~26.22dB (best-case BCH(120,106))
User payload (per bunch-clock)	160b (8b10b)	172b (worst-case BCH(40,34)) 192b (best-case BCH(120,113))

Upstream path

o ONUs -> OLT (time-division multiplexing)

o 2.4Gbps link - 8b10b encoded

1270nm

2.4Gbps

1:8
Wideband

OLT

ONU

ONU

ONU

ONU1

ONU2

Gap

Preamble

Comma/
Addr

Payload

Time slot onu1

! Minimize Waiting Time:

Number_ONU x Burst length

Upstream path

o A word on upstream overhead:

    o Burst-mode receiver dificulties: large dynamic range / short settling time

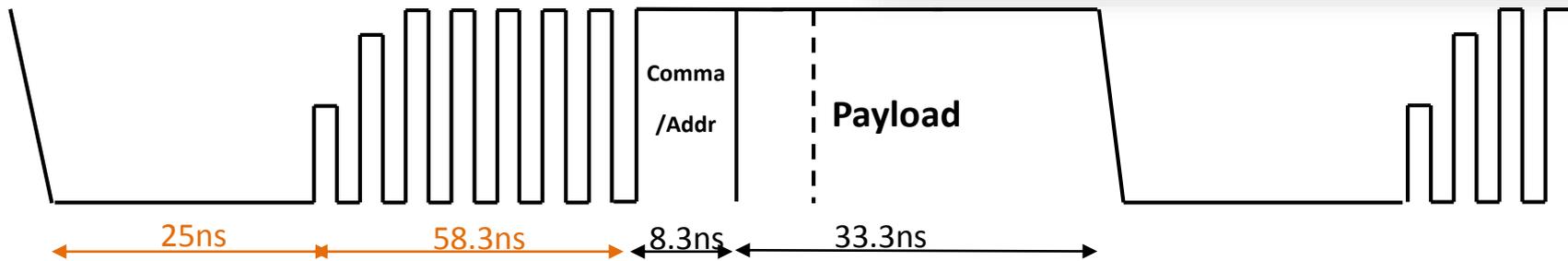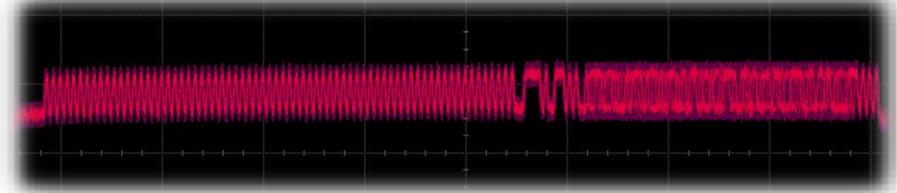   o A reset signal between bursts is needed in order to start threshold extraction
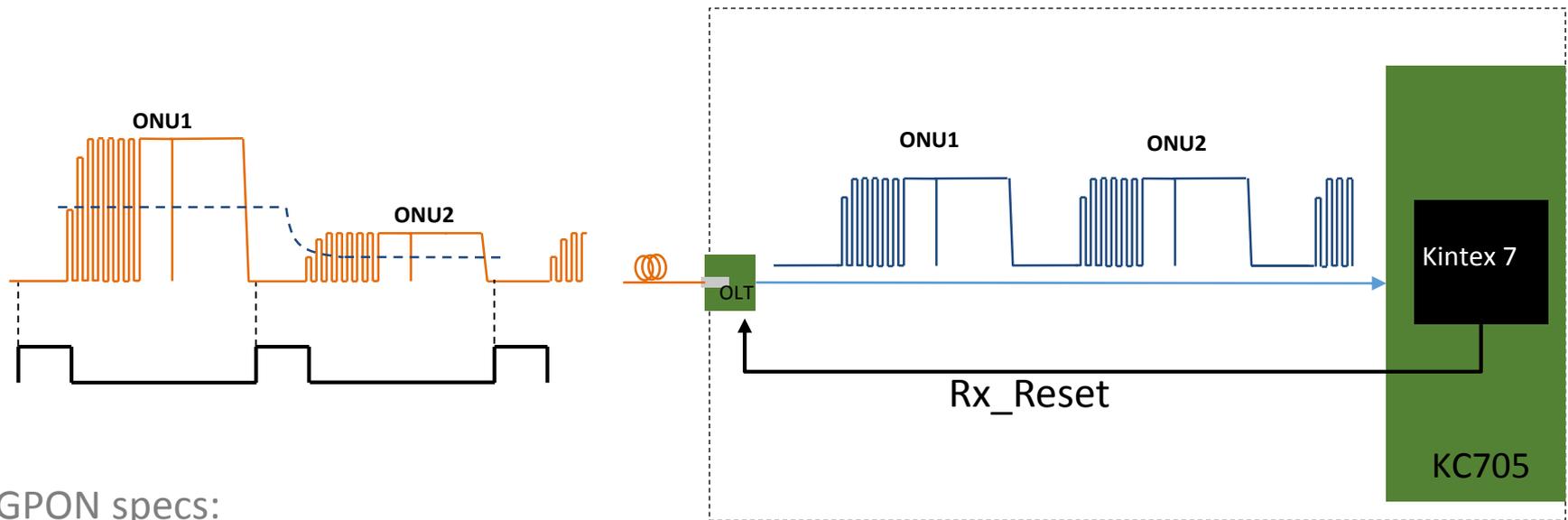
* XGPON specs:
- Minimum Gap: 25ns
- Minimum Reset Pulse Width: 25ns
- Maximum Setting time: 52ns (=minimum preamble length)

Upstream path

o Burst composition: 125ns long

| Gap	25ns
Preamble	58.3ns
Comma+Addr	8.3ns
Payload	**33.3ns (64b – 16b ctrl + 48b user)**
Total Gap+Burst	**125ns**
Latency (64 ONUs)	**64x125ns=8us**
Average data-rate (64 ONUs)	8Mbps (64b/8us)

Busy waiting time

Upstream path

o Challenges:

    o Link synchronization

    $\Rightarrow$ Clock recovery and re-use for transmit path with controlled phase (@ONU level)

    o Phase changing between bursts → classical CDR is not an option

    $\Rightarrow$ Oversampling scheme (@ OLT RX level)

    o TDM arbitration (token is automatically passed between ONUs)
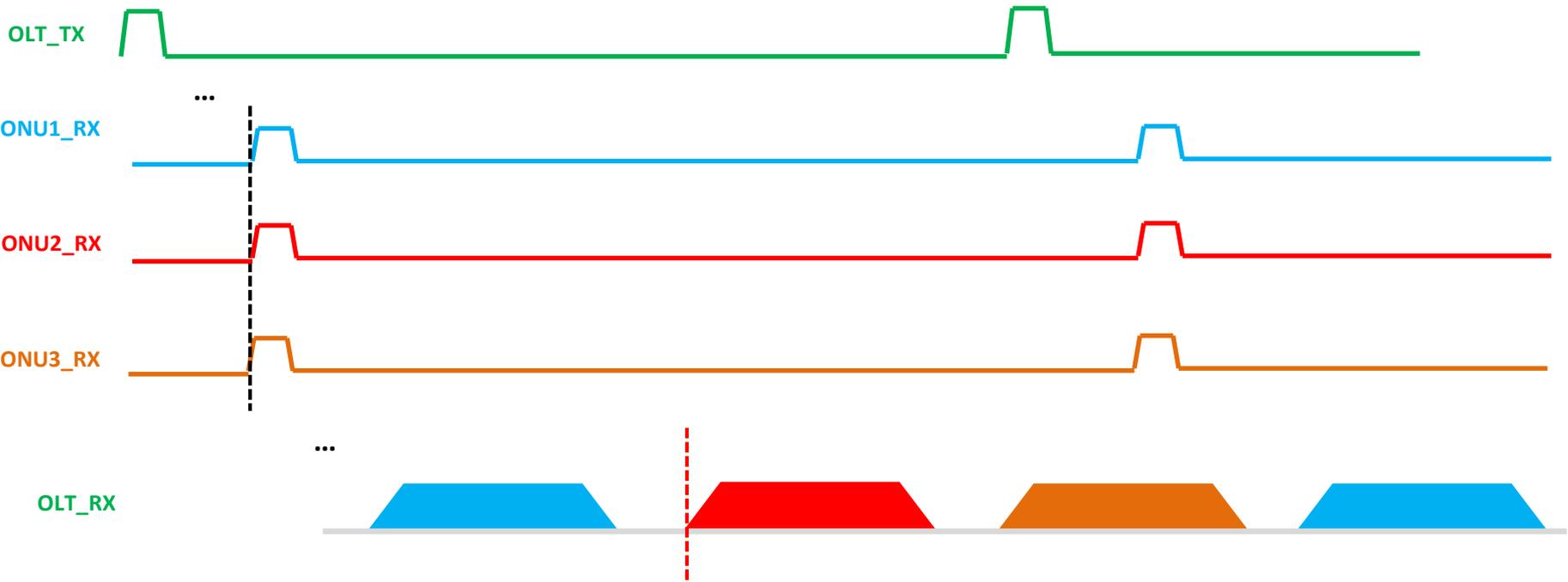
    $\Rightarrow$ Requires a calibration procedure

Upstream path

- ○ Oversampling

  - ○ Zero time-to-lock

ONU TX@2.4Gbps

| 20 bits | 0 | 1 | 0 | 1 | 0 | .... | X |

80 bits   OLT RX@9.6Gbps x4 oversampling
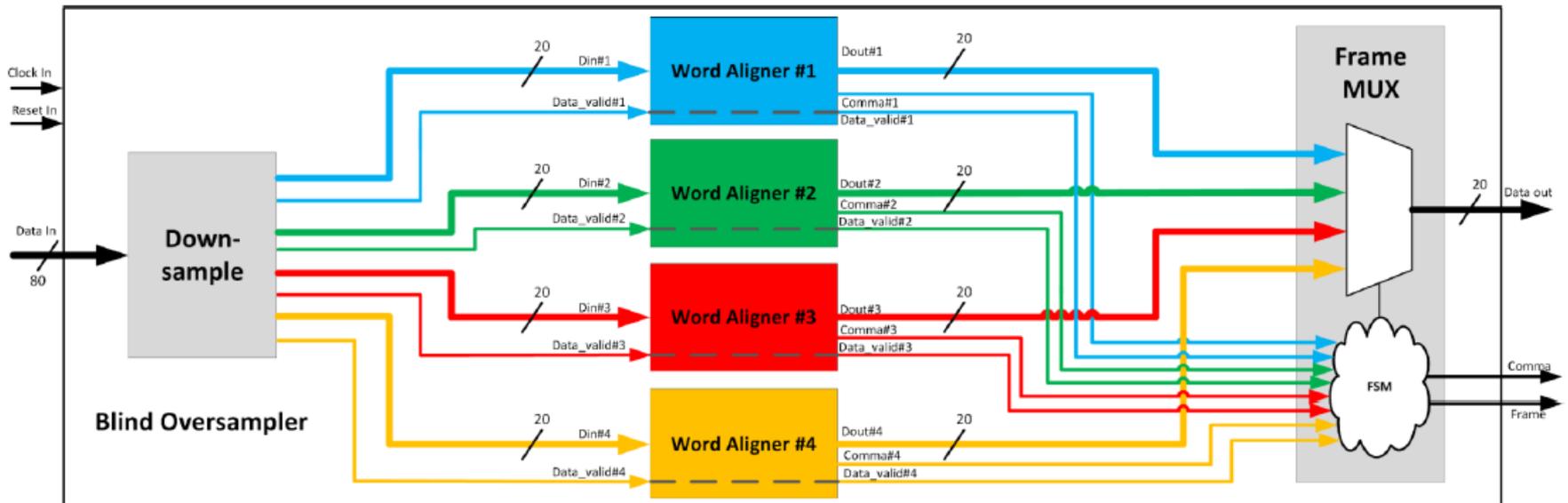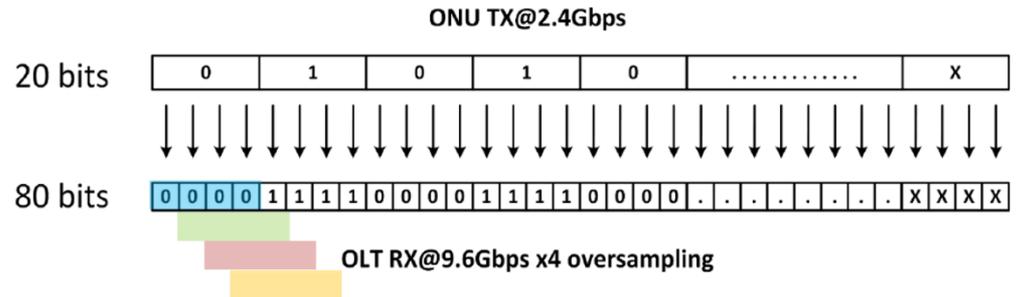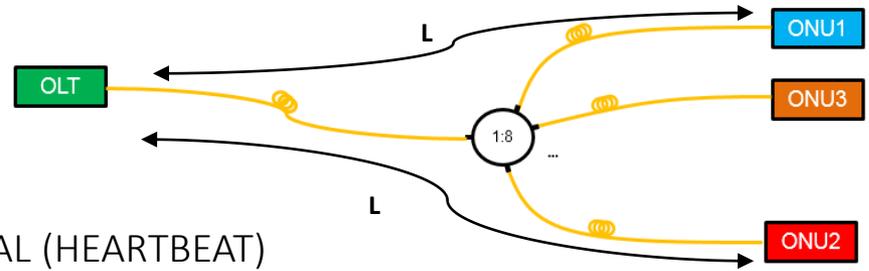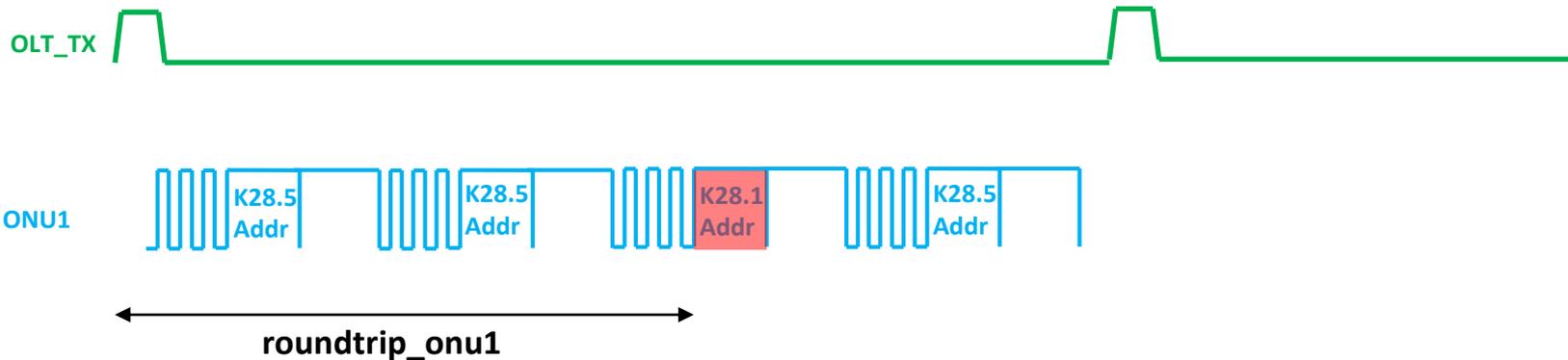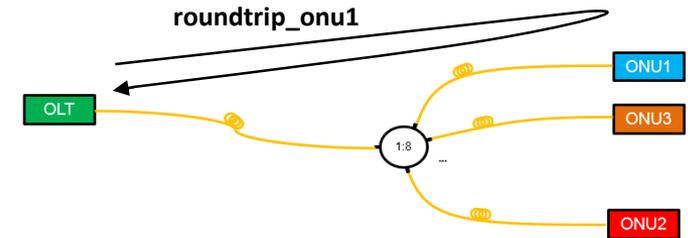
Upstream path

o TDM arbitration

 o OLT broadcast TIME REFERENCE SIGNAL (HEARTBEAT)
 o HEARTBEAT PERIOD = Number_ONUs x 125 ns
 o Each ONU has an internal counter + defined offset to transmit

Upstream path

o TDM arbitration – Calibration

o The procedure is arbitrated by the master (OLT)

o OLT measures the roundtrip time for each ONU:

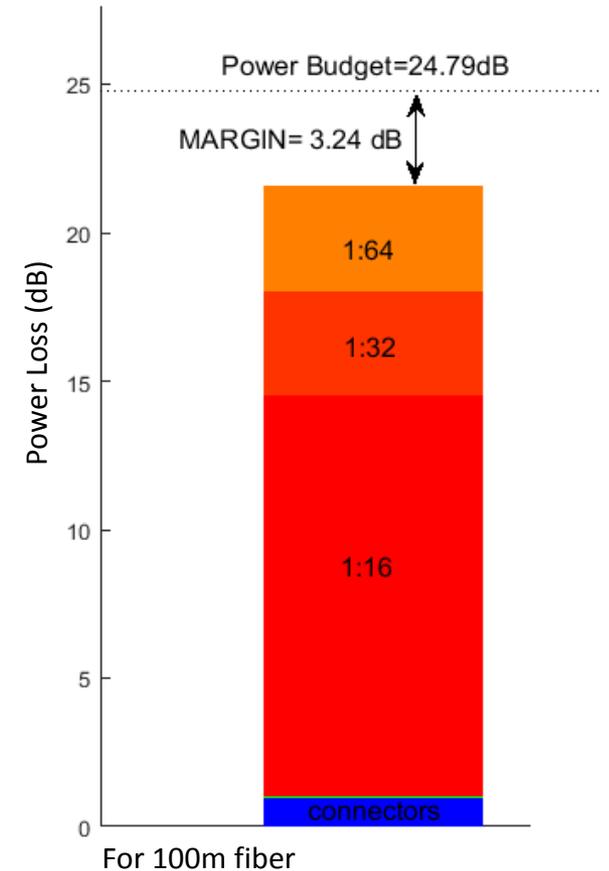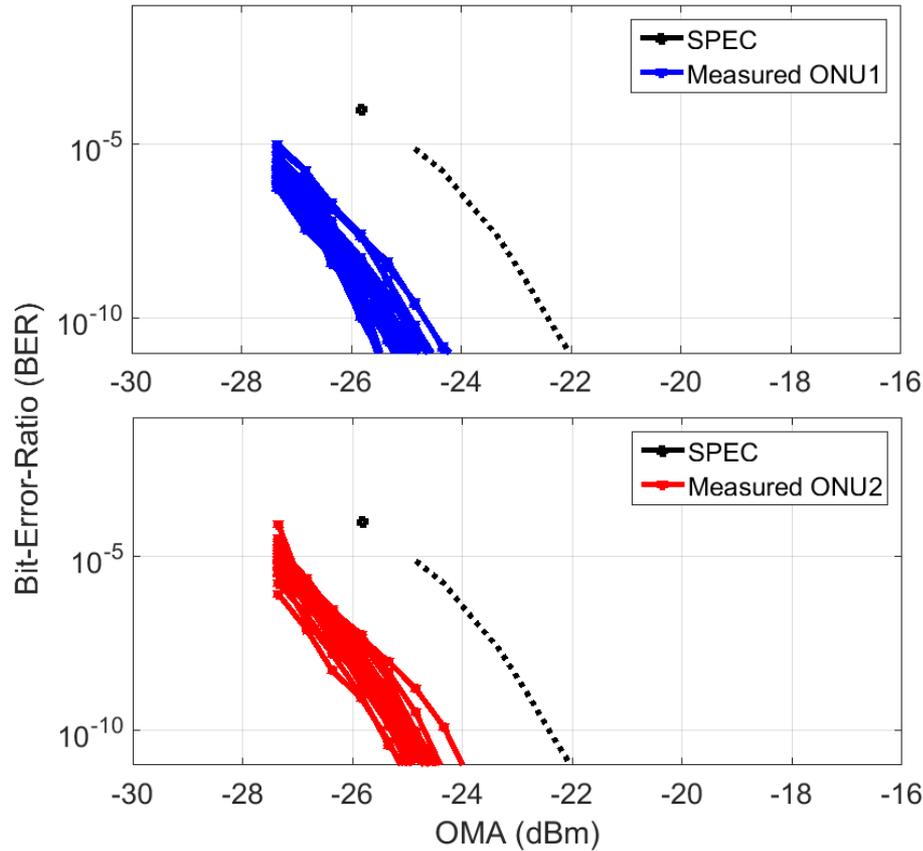o Each ONU transmits continuously during calibration (while others are OFF)

OLT_TX

ONU1

K28.5 Addr   K28.5 Addr   K28.1 Addr   K28.5 Addr
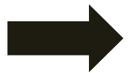
roundtrip_onu1

o ONU offset in TDM is compensated

o Timing resolution can be up to **1UI-0.416ns**

=> During run, gap can vary between 25-0.416 ns and 25+0.416 ns
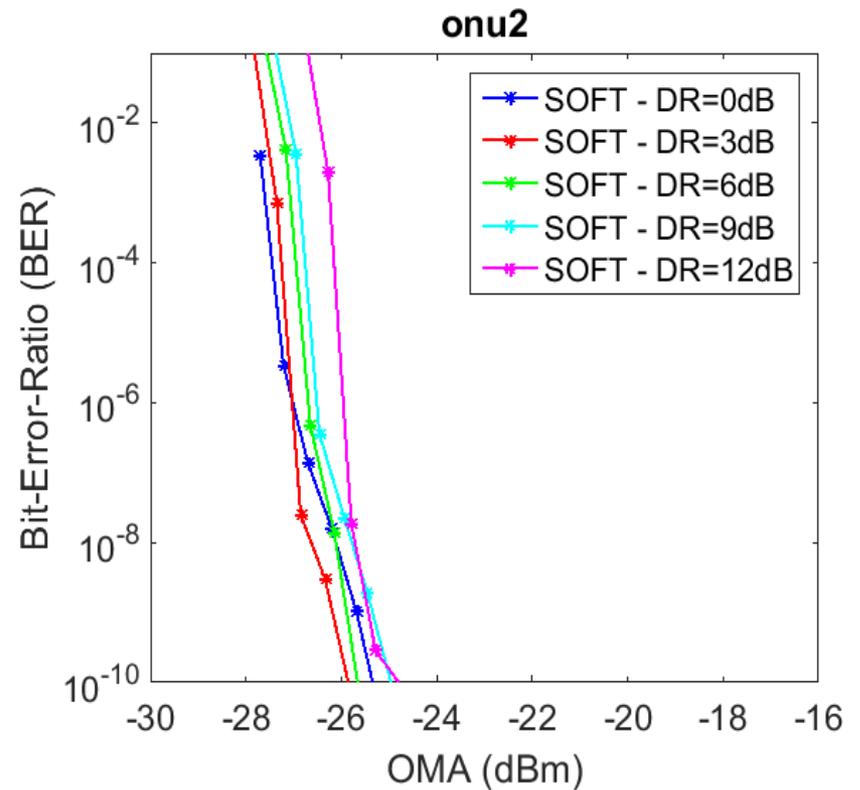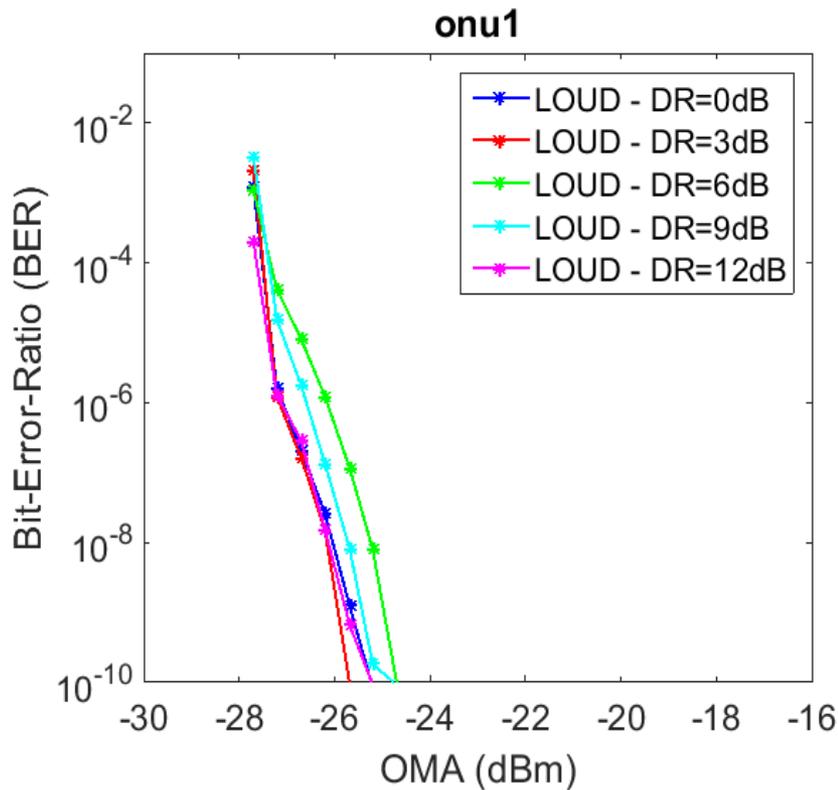
Upstream path

o **Power Budget**

Power Budget=24.79dB

MARGIN= 3.24 dB

For 100m fiber

- Target BER : 10^{-11} - CL: 0.95 – ≈10 days measurement

➡ Comfortable margin

Upstream path

o Dynamic range

o No penalty up to 12 dB

TTC-PON Core - firmware

o Core design

   o Similar structure for OLT/ONU

   o Currently implemented in
     Kintex7

   o Fully software configurable

   o Firmware started being
     delivered to users
     (collecting feedback)
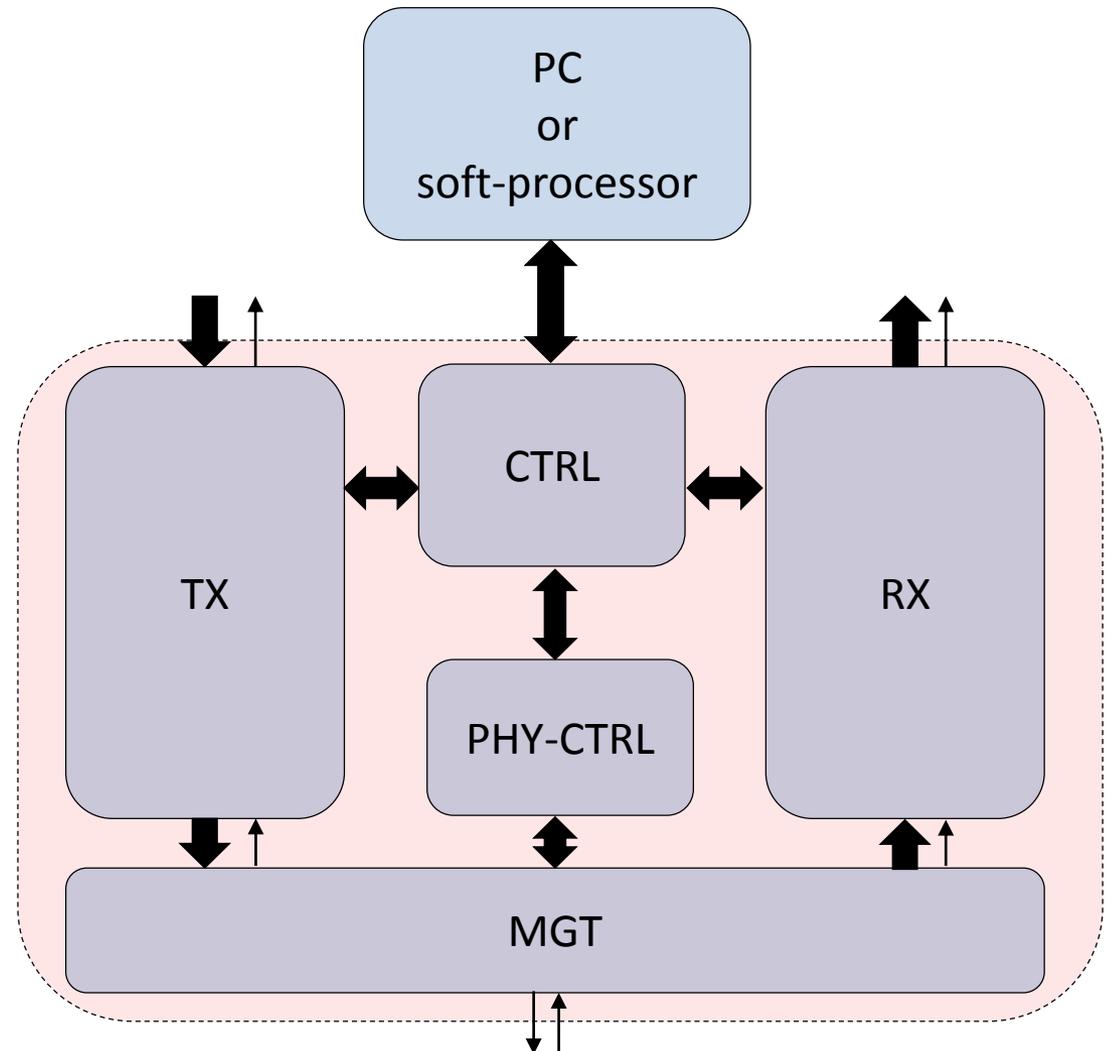

* ONU can be also controlled via OLT

Conclusions

o Simple FEC scheme could allow us gaining in power budget in order to have a safe optical margin (for 1:64 ONUs) and have a higher efficiency in downstream

o Stable upstream protocol relying on 125ns bursts was depicted

o First version of TTC-PON core IP is being delivered (collecting feedback)

o Next steps:
  o Migration to other FPGA families – Kintex Ultrascale, Arria10
  o Long BER tests
  o Temperature tests on OLT/ONU and Si5344
  o Investigate new PON standards

Potential developments for Phase-2

o Xilinx BCDR evaluation

    o [Burst Clock Data Recovery for 1.25G/2.5G PON Applications in UltraScale Devices](#)

    o [Burst-Mode Clock Data Recovery with GTH and GTY Transceivers](#)

o NGPON2

    o WDM and coloured ONUs

o XGS PON

   o Symmetric 10G PON (intermediate step between GPON and NG-PON2)
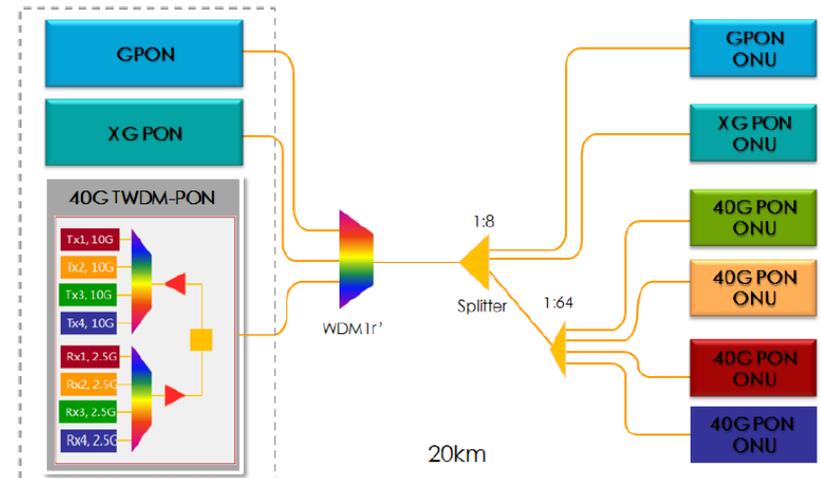
Thank You!

References

[1] I. Papakonstantinou, C. Soos, S. Papadopoulos, S. Detraz, C. Sigaud, P. Stejskal, S. Storey, J. Troska, F. Vasey, and I. Darwazeh, "A fully bidirectional optical network with latency monitoring capability for the distribution of timing-trigger and control signals in high-energy physics experiments," *IEEE Trans. Nucl. Sci.*, vol. 58, no. 4, pp. 1628–1640, Aug. 2011.

[2] D.M. Kolotouros et al., Metrics and methods for TTC-PON system characterization, 2014 JINST 9 C01015.

[3] D.M. Kolotouros, S. Baron, C. Soos and F. Vasey, *A TTC upgrade proposal using bidirectional 10G-PON FTTH technology*, 2015 *JINST* 10 C04001.

[4] Recent Developments in the TTC-PON system, S. Baron, E. Mendes, EP-ESE Electronics Seminars, 2016, https://indico.cern.ch/event/465344/

[5] Xinmiao Zhang, VLSI Architectures for Modern Error-Correcting Codes, CRC Press 2015

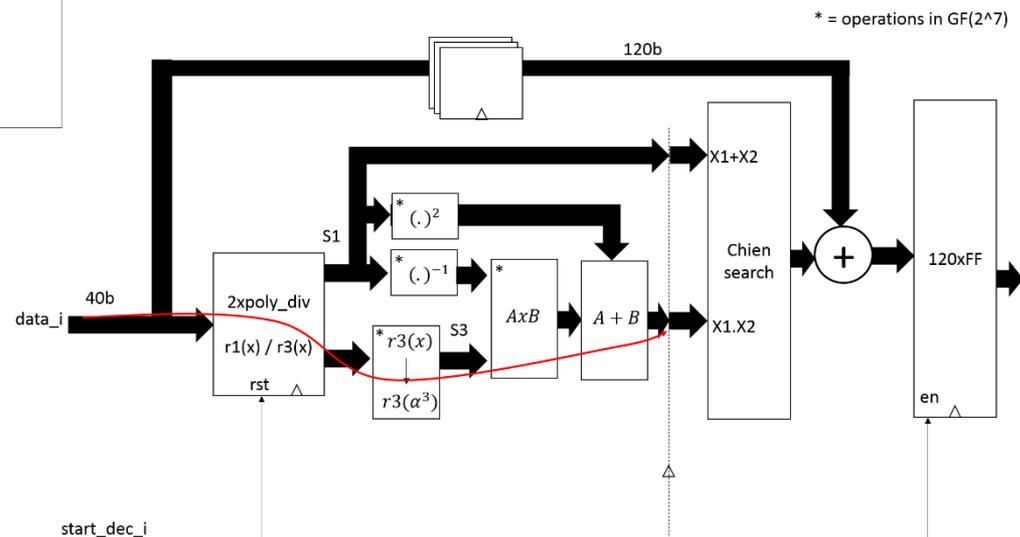# Spare Slides

TTC-PON - Setup
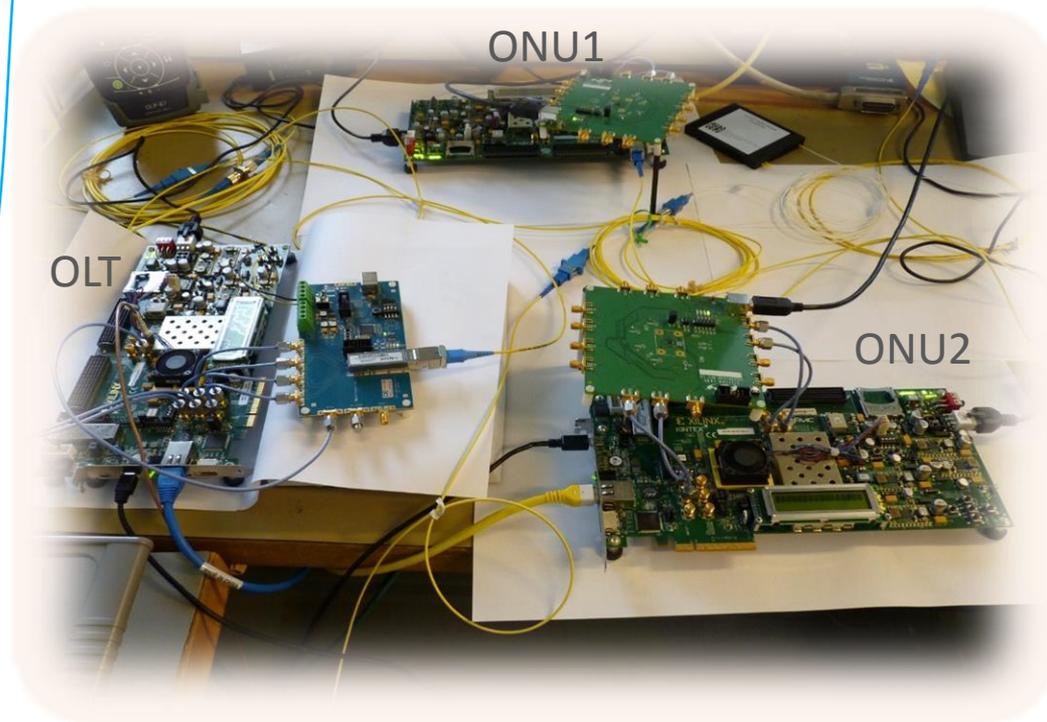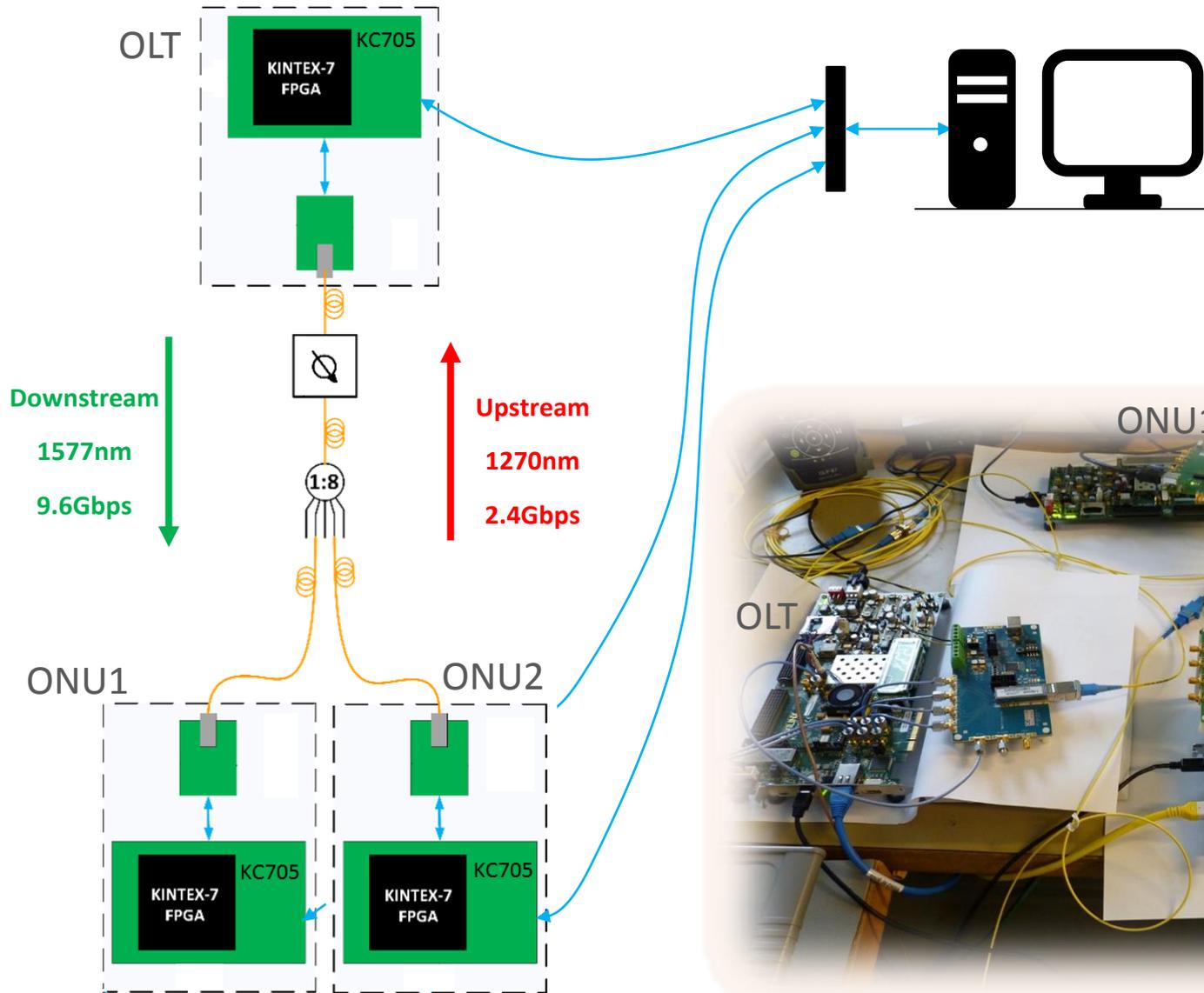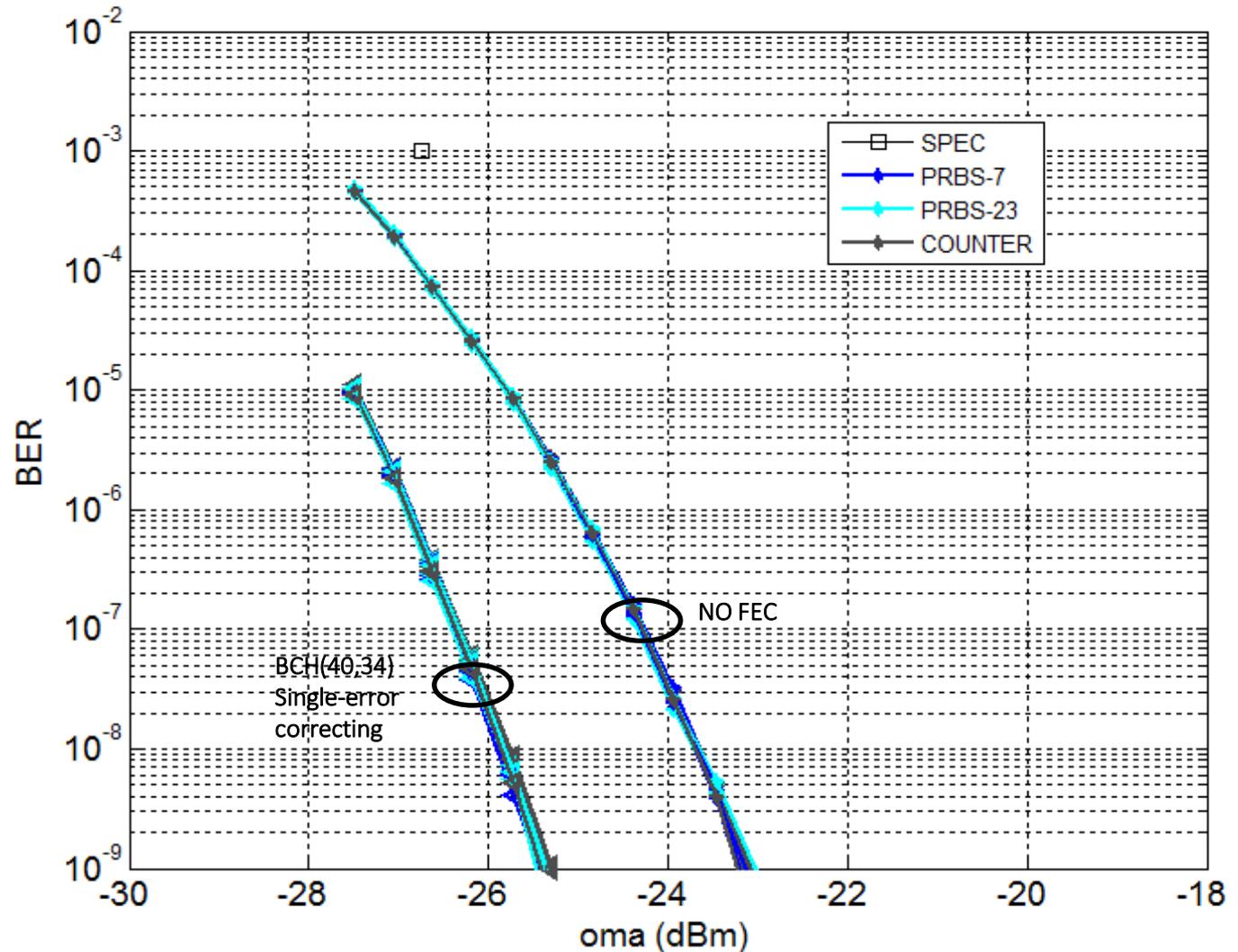
o BCH decoder – target low latency:
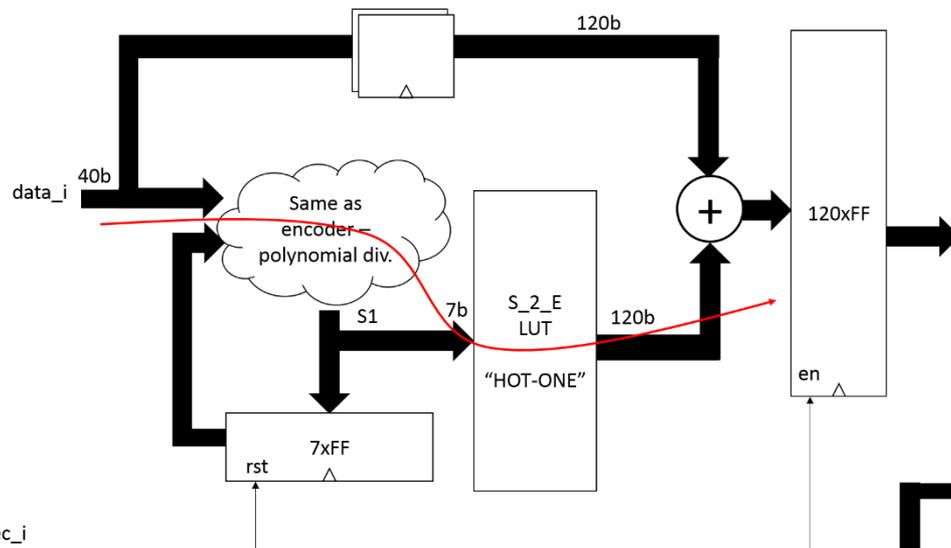
single error-correcting

double error-correcting

o Scrambling

   o Ex: $x^{43} + 1$

TTC-PON – Upstream burst length

o Burst length: 33ns x 125ns

	33ns burst	125ns burst
Gap+Preamble	16.6ns	83.3 ns (datasheet = 77.2ns)
Comma+Addr	8.3ns	8.3ns
Payload	8.3ns (16b)	33.3ns (64b)
Latency (64 onu's)	2.1us	8us
Average data-rate	7.6Mbps (16b/2.1us)	8Mbps (64b/8us)
APC	Modified	Normal (Er≈5.4dB)
Dynamic Range	~ 1.0dB	No penalty for 6dB spec
Temperature	Huge impact from 45°C	Tested up to 55°C – no impact
Sensitivity@1e-11 (OMA)	~ -24 dBm	~ -24 dBm

TTC-PON – Resources & Costs

Resource & Costing…

o Resources (of a middle range Kintex 7):

    o OLT   =~ 1% Slices LUT

    o ONU =~0.5% Slices LUT

o Cost (unit price – buying 10 components)

    o SFP+ OLT: 965 USD   / 667 USD

    o XFP+ OLT: 1075 USD / 667 USD

    o SFP+ ONU: 258 USD / 105 USD